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COST ESTIMATING RELATIONSHIP ASSOCIATING ENGINEERING DRAWING QUALITY WITH INSTALLATION COST GROWTH FOR USN SHIP ALTERATIONS

by

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Cost Estimating Relationship Associating Engineering Drawing Quality with Installation Cost Growth for USN Ship Alterations

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ABSTRACT

This is an analysis of existing feedback in the Fleet Modernization Program (FMP) planning and design process using the FFG-7 class of ships as a case study. This analysis attempts to relate the engineering drawing revision rate (inverse measure of drawing quality) and the number of ships affected by those drawing revisions (measure of availability concurrence) to the cost growth attributable to the FMP portion of U.S. Navy ship availabilities. Due to the lack of actual cost data, budget estimates were used as a surrogate and unfortunately firm relationships could not be established.

However, the methodology developed has potential for application to any large ship class which may experience numerous concurrent availabilities, as actual cost data become available. It is meant to be a tool for the engineering design agent to assess the financial impact of the quality of engineering design products on the installing activities and to assess the potential value of policy changes which improve the quality of those products.

data bases, theses, regression statistics.

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I. INTRODUCTION

The purpose of this study is to analyze existing feedback to the Fleet Modernization Program (FMP) planning and design process in an attempt to provide information for assessing the potential value of policy changes. This feedback within the system is necessary to improve the quality and efficiency of the process. In its present form, the existing feedback is inadequate for determining the financial impact that poor quality planning products may have upon the FMP.

As the Navy transitions from an extended overhaul maintenance philosophy to one of phased maintenance, the FMP planning process is gaining importance. The new maintenance philosophy coupled with greater numbers of ships means the number of availabilities accomplished each year is on the rise. In fiscal year 1987, over 100 availabilities were programmed for completion in the FMP. The annual budget is on the order of 1.3 billion dollars [Presentation to chief design engineers conference, 6 October 1987]. Since these are operation and maintenance funds, the level of funding will most likely be scaled back dramatically in the coming years which will place even more pressure on the FMP to "do more with less money". This can only be accomplished by

improving the quality and efficiency of the process through innovative, cost-effective policy alternatives.

Once ships are built, they leave the protective umbrella of the procurement world and enter the realm of maintenance and upkeep. The maintenance and upkeep functions can be decomposed into two areas of importance: 1) repair - fixing existing shipboard systems and 2) upgrade - removal of obsolete systems, improvement of existing systems, or installation of new systems. Repair planning and accomplishment is the responsibility of the ship's force, the Planning, Estimating, and Repair Activity (PERA), and the Type Commander (TYCOM). Upgrade is the responsibility of the Commander Naval Sea Systems Command (NAVSEA) which is accomplished through the FMP. The scope of this study is strictly concerned with the upgrade planning and design as accomplished through the FMP, specifically using the FFG-7 class as a case study.

A. BACKGROUND

The planning, design, and installation responsibilities for implementation of the FMP are spread among many subordinate commands which must be properly sequenced and coordinated to assure timely and efficient upgrade of specific ships. This section describes the principal players and their responsibilities. For easy reference, a glossary has been provided in Appendix A.

The Ship's Logistic Manager (SLM), located at NAVSEA headquarters in Washington, D.C., in conjunction with his counterpart in the office of the Chief of Naval Operations, programs specific ship alterations (SHIPALT's) for accomplishment on individual ships during their respective availabilities. Additionally, the SLM tasks the Expanded Planning Yard (EPY), responsible for his ship class, with SHIPALT development for future accomplishment.

The EPY, as the design agent, is responsible for SHIPALT development for a given ship class. He produces all installation drawings for each SHIPALT and tailors those drawings to each specific ship. A list of applicable drawings along with the drawings themselves are then provided to the activities responsible for installation of the SHIPALT's on each ship to facilitate writing and award of contracts.

In the case of public sector availabilities, i.e., those accomplished by Naval Shipyards, the responsible Supervisor of Shipbuilding and Ship Repair (SUPSHIP) merely issues the work specifications to the installing shipyard and the funding for the work comes directly from NAVSEA to the shipyard. The other case is that of availabilities serviced by the private sector, in which the SUPSHIP issues a contract to a private shipyard and the funding comes from NAVSEA via the responsible SUPSHIP, who is the contracting agent, to the installing shipyard.

For either case, the specifications for improvements to a ship are based on, and referenced to, the drawing schedule (list of applicable drawings) provided by the EPY to the responsible SUPSHIP approximately twelve months prior to the ship's availability start date [Ref. 1]. In the past, when the number of ships in a class was relatively small (less than 10 or 15) and the maintenance philosophy was centered around an intensive overhaul every five years, this lead time presented no problem since availabilities rarely overlapped. No overlap meant lessons learned on one availability could be incorporated easily into the next subsequent contract. Currently, with the existence of several large ship classes (FFG-7, DD-963, etc.) of more than 20 ships each, accompanied by a phased maintenance philosophy which calls for short availabilities every two years, concurrent availabilities are unavoidable. This creates the situation in which a poor drawing encountered on one installation can affect several other concurrent installations as well as any upcoming availabilities in which the contract is already awarded. This effect will be referred to throughout this study as the "snowball" effect. To resolve drawing deficiencies, the basic drawings must be revised and the drawing schedules updated to reflect the revised drawings. Obviously, as the revision rate increases, the drawing schedules will become obsolete much more rapidly.

Review of contract completion reports for FFG-7 class availabilities during 1985, 1986, and 1987 revealed two contributors to contract cost growth on FMP items. The first, incomplete specifications which do not reference the proper drawings (due to an obsolete drawing schedule), manifests itself as a costly contract modification early in the availability to incorporate the correct drawings. The second, drawing deficiencies encountered during installation, manifest themselves as contract modifications throughout the availability period. In addition, associated government delay and disruption charges may be a source of cost growth which lingers long after availability completion during potential litigation.

Drawing deficiencies, hypothesized as a variable directly associated with cost growth during FMP implementation, are the root of the problem addressed in this study. The basic problem is that existing feedback to the EPY in the form of Liaison Action Records (LAR's) is inadequate for the EPY to assess the impact of its product quality on the installing activities.

To avoid any additional accounting or administrative burdens on the installing activities, this study attempts to relate installation cost growth to the LAR as the indicator of EPY product quality, in this case drawings and drawing schedules. Hopefully, this will in turn enable the EPY to

conduct an educated cost-benefit analysis when considering options for improving the quality of their products.

B. ORGANIZATION

The next chapter explains the steps taken to obtain a viable data base for establishing the relationship between design deficiencies and cost growth. It will also cover definitions of the key variables and all adjustments made to the raw data to make it commensurable.

The third chapter covers the model development. The fourth chapter includes results and conclusions about the model and its shortcomings along with significant problem insights obtained during model development. Chapter five consists of recommendations for further study. All raw data and adjusted data are appended at the end of the study.

II. DATA BASE SELECTION/DEVELOPMENT

A. SELECTION PROCESS

Once the problem was defined as discussed, the crucial issue became one of finding a suitable data base from which to derive the desired relationship. The search for a data base appeared to be easy at first glance, but required three iterations, with increasing numbers of assumptions at each stage. This chapter outlines the data desired, definitions, and the actual data obtained for the study.

1. Initial Concept

The first "rough cut" at tying increased installation costs to EPY drawing revisions was attempted at a "micro" level. Specific Liaison Action Records and their associated drawing revisions for the FFG-10's availability conducted in Long Beach, CA between September and December 1985 were recorded and the resultant list was taken to SUPSHIP Long Beach, CA who contracted the availability. Using the Contract Completion File, an attempt was made to account for the cost growth by associating a contract modification with each LAR.

This approach proved to be infeasible for two reasons. The first is that contract completion files are not centrally located, i.e., each SUPSHIP maintains them at

their location. Additionally, the files are hard copy only, which requires an investment in time to learn the idiosyncracies of each SUPSHIP's filing system. Had the resources been available to visit each cognizant SUPSHIP and review their files, this data could have been collected, but the research would not have been productive for the second reason.

The second problem with this approach, the fixed price contracting policy of the Navy during the period being studied, made it virtually impossible to associate a contract modification with any one item. Each contract modification was a lump sum increase/decrease to the contract award price arrived at through negotiations with the contractor for a group of items. For the contract reviewed, only about 38% of the LAR's on the list were eventually recorded as contract modifications.

2. Concept Modification Number 1

To avoid the complications associated with a "micro" approach, the next attempt was to look at installation cost growth as the difference between the final contract cost and the initial contract award price. This approach too, had complications which made it unworkable for this study. In the future, the complications can be overcome making this the most promising approach for future studies.

Due to fixed price contracting, it is not possible to directly separate cost growth in the repair package from

cost growth in the FMP package. This can be overcome through SUPSHIP estimates of NAVSEA's share of the award price and the completion price. The difference between these two figures would represent the growth attributable to NAVSEA. Additionally, by referencing the data base to be described in the next section, any growth due to changes in contract scope[1] can be taken into account.

The other complication which presently makes this option undesirable is that the majority of SUPSHIP's involved with FFG-7 work did not come on line with the Navy's automated accounting system (STAR) until mid- to late-1986. This leads to the same complication as the initial concept -- scattered, hardcopy records. To obtain a complete data base for the period of the study (1985 - May 1987) would require visiting individual SUPSHIP's to obtain contract completion data for availabilities they administered prior to coming on-line with STAR. Worth noting here, by the end of FY88, enough complete data will be in the STAR data base (a long enough period of expenditure information to be of use) to make this a viable approach.

3. <u>Concept Modification Number 2</u>

Since actual cost data were not readily available,

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[1]. Changes in scope are modifications which add new work or delete existing work in the contract as opposed to changes within scope which are modifications to procedures or drawings pertaining to existing work in the contract.

an alternative data base of funding and fiscal program data for the FMP (SAFIRE) was explored. This data base contains only FMP information so the previous problem of separating repair and modernization costs does not exist. Additionally, changes in availability cost due to changes in scope can be accounted for by looking at the current amount programmed through the escrow account for each hull.

To define availability cost growth, the following assumptions were made: 1) the current amount programmed for a given ship is an accurate and consistent estimate of its actual availability end cost and 2) the amount funded to the contracting SUPSHIP is approximately the contract award price. With these two assumptions, growth was defined as the difference between the amount programmed and the amount funded. This crude definition of growth actually reflects the accuracy of NAVSEA's budget estimates rather than any actual cost growth, but will be used as a surrogate measure of actual cost growth.

B. VARIABLE DEFINITIONS

1. Response Variable - Cost Growth

Despite the foregoing discussion, growth by hull was defined as the difference between the current amount programmed and the total amount funded as documented in the SAFIRE (budget execution subsystem) data base (see Appendix B). To develop the time series data for the model, the growth for a given hull was first adjusted to constant East

Coast, 1986 dollars (see Appendix C), and then averaged over the number of days the ship was in an availability to arrive at an average daily cost growth figure for each hull. The temporal and regional adjustments to the data base will be discussed below. The average daily growth figure was then multiplied by the number of days the ship spent in its availability each month to arrive at an average growth figure for each month of the availability. These monthly growth figures were then summed over all ships in an availability for a given month (see Appendix D). The result was 29 periods of average monthly cost growth for the FFG-7 class between January 1985 and May 1987. Specifically left out of the data base were the FFG-8 and the FFG-16. Their respective availabilities were unique and of extended duration.

2. Explanatory Variables

a. Revision Rate

As discussed in the introduction, the revision rate experienced by the BPY is the only consistent feedback they receive concerning their products -- drawings. This was chosen as the measure of BPY drawing quality. Theoretically, a high revision rate at the BPY should be reflected by a large amount of cost growth during installation. To quantify revision rates, LAR's were reviewed and counted only if they required a drawing revision for resolution. These LAR's usually carried a

comment to the effect, "information only, no drawing revision required". This eliminated the LAR's which were submitted by contractors who did not know what they were doing or who were trying to make up for a low bid. Additionally, since a LAR is submitted for one problem only, if several drawings required revision as a result, it was counted as only one revision. Again, the LAR's are filed by hull and to get the time series data, the LAR's had to be summed across all hulls in a given month. The date of a revision was taken to be the estimated drawing completion date rather than the actual date of the LAR, to establish when it would affect other ships.

b. Reverse LAR's

To reflect how many other ships are affected by a revision, the most accurate indicator is the number of reverse LAR's issued. When a LAR requires drawing revisions, a reverse LAR is issued to all ships whose drawing packages are affected, and whose contracts have already been awarded. The advantage of using reverse LAR's is that unaffected ships (those not receiving a given SHIPALT or who already have the SHIPALT) are not counted. Unfortunately, the reverse LAR program was not started until 1986, resulting in an incomplete data base for the period of the study. Therefore reverse LAR's were not used.

c. Number of Ships Affected

The next best measure to capture the "snowball" effect of making drawing revisions is to look at all ships which could be affected. This number is actually an upper limit on the number of reverse LAR's issued. Arguably, the FMP requires contract award by 6 months prior to availability start date, however, empirical observation of actual award dates with respect to availability start dates showed 4 months is closer to the norm. For the purpose of this study, number of ships affected was defined as all ships in an availability or within 4 months of availability commencement for a given month.

C. ADJUSTMENTS TO GROWTH DATA -- '86, EAST COAST DOLLARS

To make the cost figures commensurable, two factors had to be considered. Temporal differences, ie., inflation, had to be taken into account as well as regional differences in labor rates. These factors could be incorporated using two different approaches: 1) by blocking the data and using two additional explanatory variables in the model or 2) adjusting the data base for the two effects prior to model development. The first approach was rejected since it would require a further reduction in degrees freedom in a model which already is data limited. The second approach was accomplished as follows.

1. Temporal Adjustments

The growth data were adjusted to 1986 dollars. Using Bureau of Labor Statistics monthly labor indices for the shipbuilding industry, an inflation index for 1985 and a deflation index for 1987 were derived by taking the difference between the average index level for the year being adjusted and the average index level for the base year and normalizing to the base year. These indices were then applied to their respective groups of availabilities. The 1985 index was 1.029 and the 1987 index was 0.989.

2. Regional Adjustments

Due to the wide geographic distribution of shipyards, regional differences in labor rates exist. Traditionally, the shipbuilding industry avoids this consideration by converting all dollar amounts to manhours of labor. Rather than lose the magnitude of the growth through a linear transformation to manhours, the growth figures were simply transformed to constant location dollars, in this case the East Coast. The Navy regularly compiles labor rates for each contractor, however the data is business sensitive and the additional gain in accuracy of adjustments are not deemed significant. The U.S. Department of Transportation's Maritime Administration publishes an annual report on the Relative Cost of Shipbuilding which

establishes regional ratios relative to the Atlantic Coast [Refs. 2,3]. The indices from that source are in Table 1.

Each year's regional indices were applied to the group of availabilities in each respective region. The adjusted growth data and availability dates are in Appendix C. The entire set of time series data are in Appendix E.

TABLE 1
RELATIVE SHIPBUILDING COSTS

YEAR	PACIFIC COAST RATIO TO ATLANTIC COAST
1985	1.032
1986	0.998
1987	1.054*

* NAVSEA estimate

III. MODEL DEVELOPMENT

A. FUNCTIONAL FORM

In developing a relationship between revision rate and cost growth and attempting to capture the snowball effect, several functional forms of the variables were investigated. Initially, only revision rate was used as an explanatory variable. It became apparent that revision rate by itself did not reflect how many ships were being affected by each revision. The progression was from a simple linear relationship to increasingly complex, intrinsically nonlinear forms. The nonlinear forms did become linear upon taking natural logarithms, allowing the use of a standard linear regression package.

1. Linear Forms

Regressing growth on revision rate alone yielded unsatisfactory results by virtually all measures of model performance. The next alternative was regressing growth on the number of ships affected which yielded the best results for a linear model, but even these were inadequate. The final alternative explored was a regression of growth on the revision rate and the number of ships affected. This model estimated a negative coefficient for revision rate which intuitively was not correct. Table 2 lists the summary statistics for the various alternatives and Figures 1 and 2

represent the fit of this form of model. The effects indicated by the Durbin-Watson statistic are discussed below.

TABLE 2

REGRESSION STATISTICS FOR LINEAR FORMS

Variant)	Estimated Coefficients (Significance Level)		
1) G =	2.77E5 (0.032)	+ 19215.45(R) (0.214)	
	R-SQ = 0.21	D-W = 0.519	
2) G =	-4.00E5 (0.072)		+ 94785.06(N) (0.001)
	R-SQ = 0.34	D-W = 0.509	
3) G =	-4.47E5 (0.051)	- 15366.23(R) (0.330)	+112720.1 (N) (0.001)
	R-SQ = 0.34	D-W = 0.519	

G - Growth
R - Revision Rate
N - Number of Ships Affected

R-SQ - R-Squared Statistic
D-W - Durbin-Watson Statistic

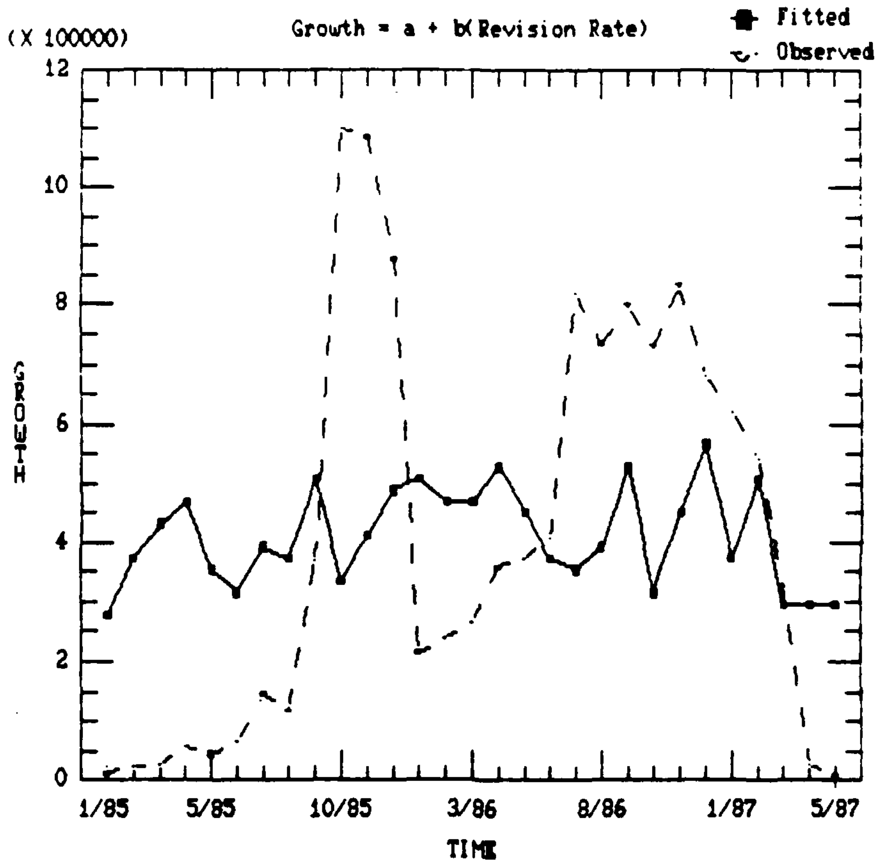

Figure 1. Predicted and Observed Values vs. Time

Linear Model

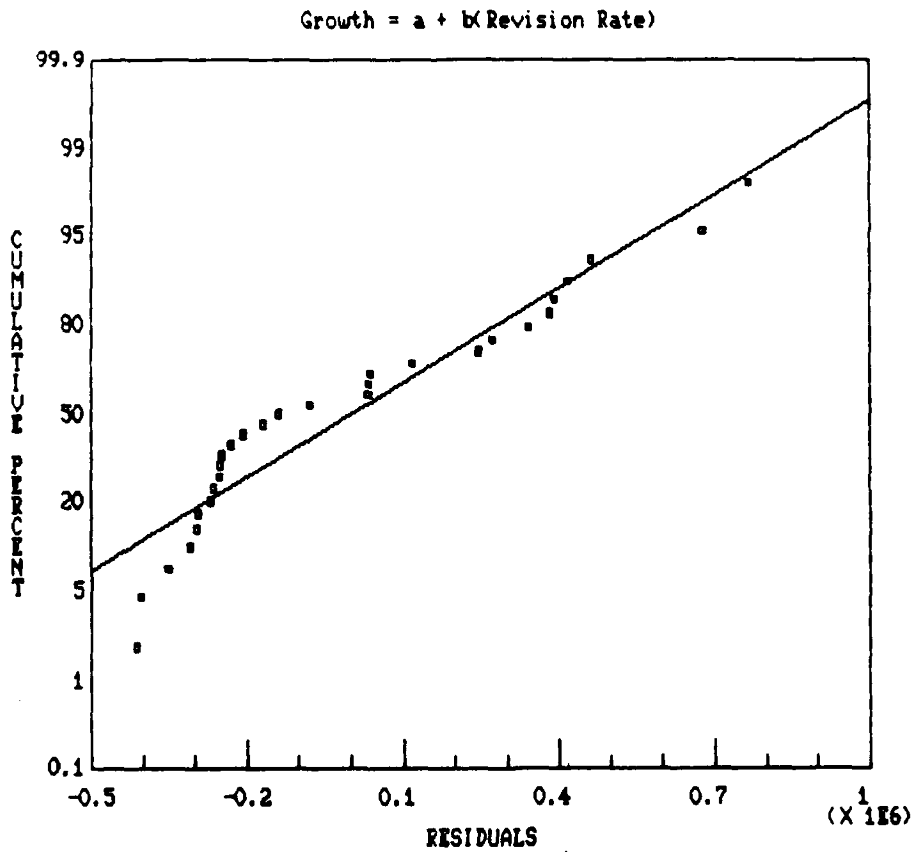

Figure 2. Normal Q-Q Plot

Linear Model

2. Intrinsically Nonlinear Forms

After exhausting the simple linear models, some linear regressions with nonlinear interpretations were examined. Regressions of this form allow for multiplicative and exponential relationships among the explanatory variables. This type of model is intuitively the most appealing, since it can capture the essence of the snowball effect of drawing revisions.

a. Log / Semi-log

The first of these models attempted was obtained by regressing the natural logarithm of growth on the revision rate, the number of ships affected and then both. This class of models was a significant improvement over the linear models in that the coefficients corresponded to the best fit of an exponential model in terms of the explanatory variables. In other words, the regression was of the form,

$$\text{Ln(Growth)} = a + b(\text{Revision Rate})$$

which implies an underlying model of the form,

$$\text{Growth} = \text{EXP}\ (a + b(\text{Revision Rate})).$$

In this form, the fit was still not adequate and the residuals were not properly distributed.

At this point, the initial signs of upcoming problems also started to appear. The model, with the number of ships affected as its only variable, had a much better fit than the model with only revision rate as the explanatory variable. To confirm the apparent lack of

effect of revision rate, a model with both revision rate and number of ships affected as explanatory variables yielded a regression coefficient for revision rate which was not significantly different from zero. Additionally, the Durbin-Watson statistic and the residual plots indicated a high degree of serial correlation (see Table 3). Draper and Smith [Ref. 4:pp. 162 - 169] provide a very concise discussion on the derivation and significance of the Durbin-Watson statistic.

TABLE 3

REGRESSION STATISTICS FOR LOG/SEMI-LOG FORMS

Variant)	Estimated Coefficients (Significance Level)		
1) lnG =	11.16 (0.000)	+ 0.15(R) (0.017)	
	R-SQ = 0.16	D-W = 0.656	
2) G =	8.08 (0.000)		+ 0.48(N) (0.000)
	R-SQ = 0.48	D-W = 0.419	
3) G =	8.11 (0.001)	- 0.01(R) (0.884)	+ 0.48 (N) (0.001)
	R-SQ = 0.46	D-W = 0.423	

G - Growth
R - Revision Rate
N - Number of Ships Affected

R-SQ - R-Squared Statistic
D-W - Durbin-Watson Statistic

Figures 3 and 4 are representative of the quality of fit of this model form. Note the poor distribution of residuals indicated by Figure 4.

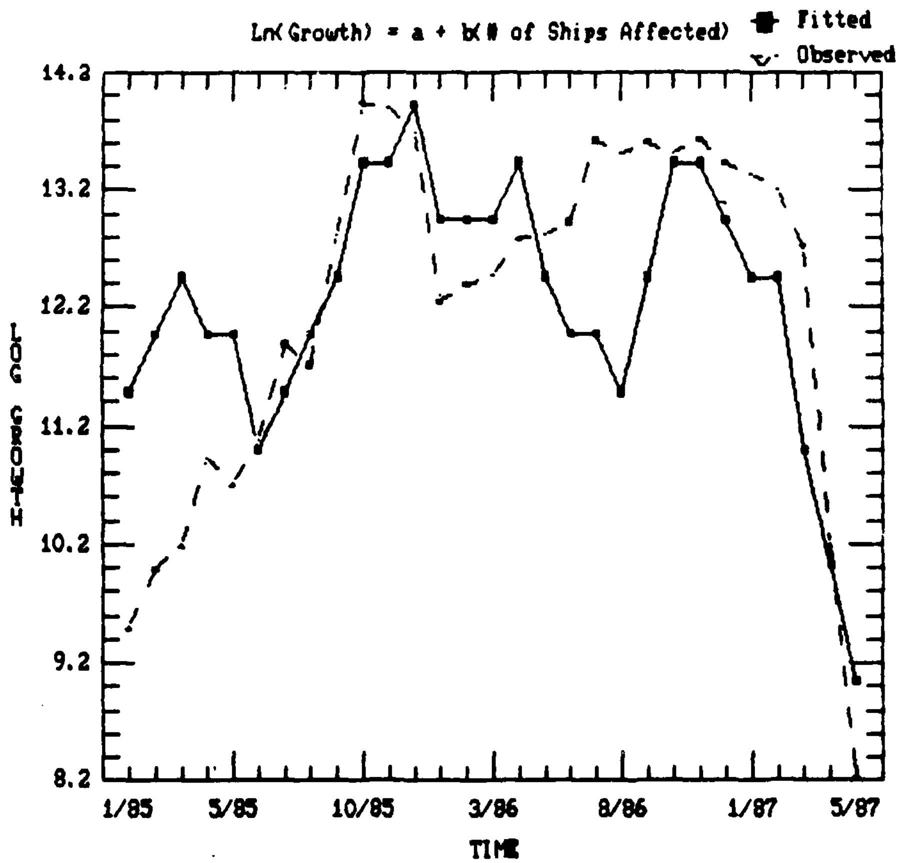

Figure 3. Predicted and Observed Values vs. Time

Log / Semi-log Model

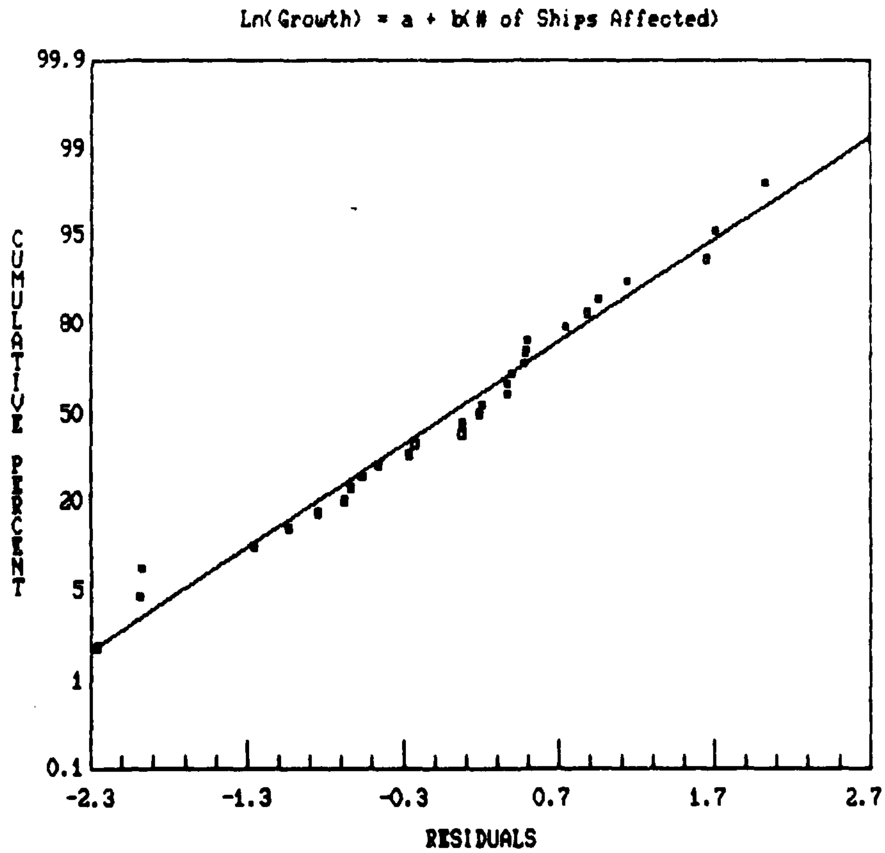

Figure 4. Normal Q-Q Plot

Log / Semi-log Model

b. Log / Log, Log / Mixed

This class of models was an attempt to do three things: obtain a better fit, obtain more normally distributed residuals, and explore some additional possible relationships of the explanatory variables. In the Log / Log models with the natural logarithm of growth regressed on the natural logarithm of revision rate alone, number of ships alone, and both together, the regression coefficients represent powers of exponentiation of the explanatory variables. The regression was of the form,

$$\mathrm{Ln(Growth)} = \mathrm{Ln}(a) + b\ (\mathrm{Ln(Revision\ Rate)})$$

which implies an underlying model of the form,

$$\mathrm{Growth} = a\ (\mathrm{Revision\ Rate})^{b}.$$

These models provided a better fit, but with the exception of number of ships alone, were not very stable since the fitted line was significantly influenced by a small number of outliers. At this point, the residuals appeared to be normally distributed but still were serially correlated (see Figure 5). Table 4 shows the summary statistics for this set of alternatives.

The final model explored was a hybrid of the first two types. The natural logarithm of growth was regressed on the natural logarithm of the number of ships affected and

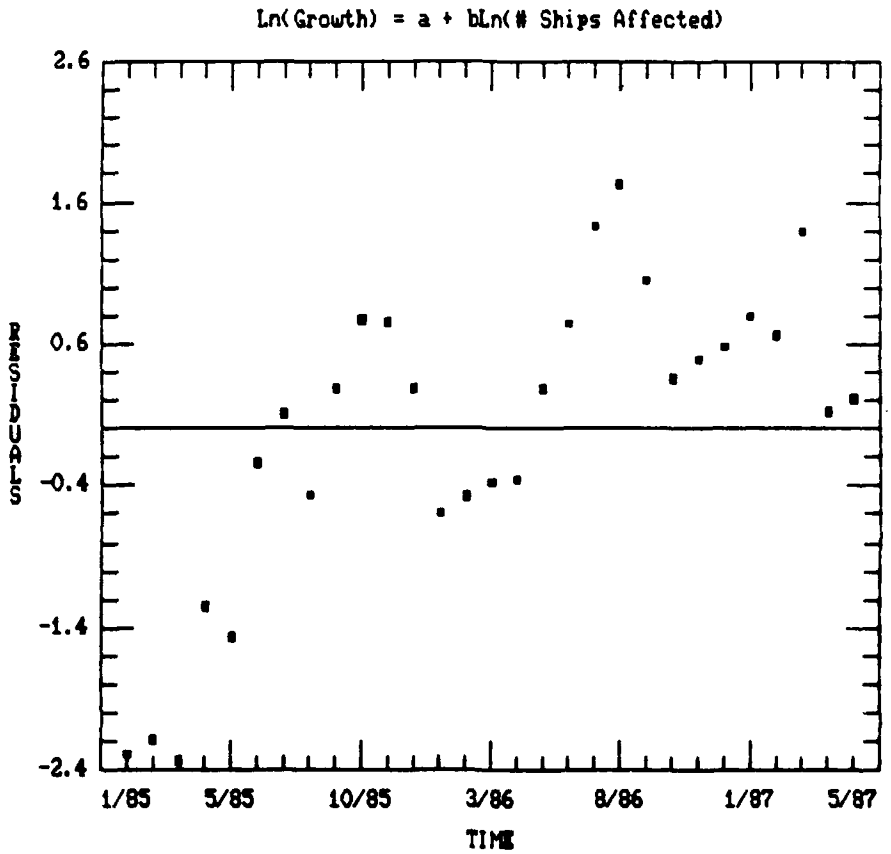

Figure 5. Residuals vs. Time

Log / Log Model

the raw revision rate. In this case, the regression was of the form,

$$Ln(G) = a + b\ (Ln(N)) + c\ (R)$$

where G is the growth, N is the number of ships affected,

TABLE 4

REGRESSION STATISTICS FOR LOG/LOG FORMS

Variant)	Estimated Coefficients (Significance Level)		
1) lnG =	11.02 +	0.77(lnR)	
	(0.000)	(0.023)	
	R-SQ = 0.15	D-W = 0.591	
2) lnG =	5.90	+	3.02(lnN)
	(0.000)		(0.000)
	R-SQ = 0.48	D-W = 0.292	
3) lnG =	5.72 -	0.29(lnR)+	3.38 (lnN)
	(0.000)	(0.397)	(0.000)
	R-SQ = 0.51	D-W = 0.402	

G - Growth
R - Revision Rate
N - Number of Ships Affected

R-SQ - R-Squared Statistic
D-W - Durbin-Watson Statistic

and R is the revision rate. This implies an underlying model of the form,

$$G = a\ (N)^b\ EXP\ (c(R))$$

This model yielded a good fit and normal residuals, but the coefficient for revision rate was still not significantly different from zero and the Durbin-Watson statistic indicated a strong positive serial correlation (see Table 5). Figures 6 and 7 demonstrate the fit obtained with this model.

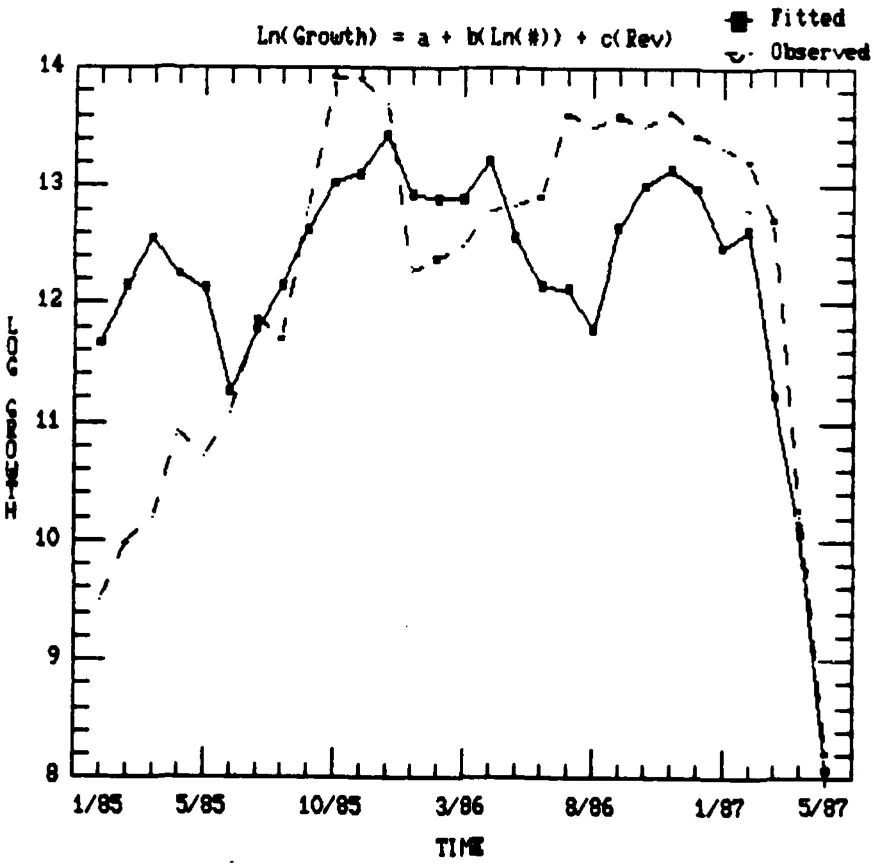

Figure 6. Predicted and Observed Values vs. Time

Unadjusted Hybrid Model

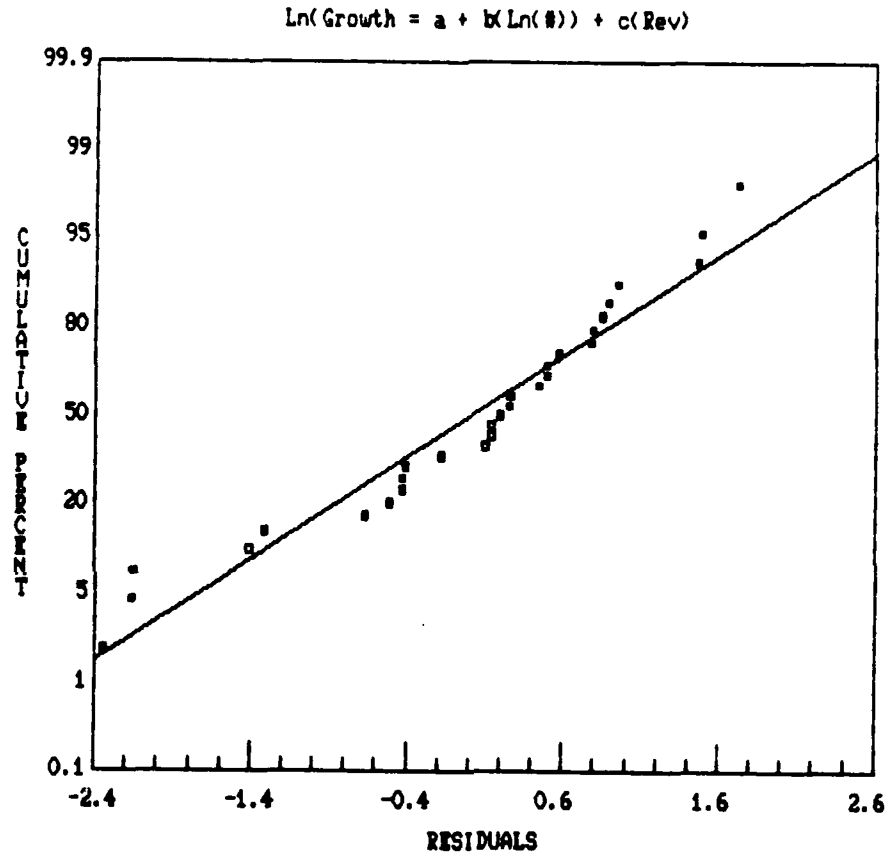

Figure 7. Normal Q-Q Plot

Unadjusted Hybrid Model

B. ADDITIONAL CONSIDERATIONS - SERIAL CORRELATION

Once the various model forms had been explored, the problem of serial correlation remained to be resolved. Using the hybrid model as the "best" (the most potential) case, an autocorrelation coefficient was estimated using the Durbin-Watson statistic and the variables were then adjusted in the manner described by Judge, et al. [Ref.5:pp. 439 - 444](see Appendix F). The regression on the adjusted variables yielded a much better fit and much better residuals (see Figures 8 and 9) but the coefficient for the revision rate was still not significantly different from zero in the adjusted model (Table 5).

TABLE 5

REGRESSION STATISTICS FOR HYBRID FORM

Variant)	Estimated Coefficients (Significance Level)				
			Correlated		
1) lnG =	6.05	+	0.02(R)		2.88(lnN)
	(0.000)		(0.737)		(0.000)
	R-SQ = 0.47		D-W = 0.311		
			Adjusted		
2) lnG =	1.01	-	0.02(R)	+	3.17(lnN)
	(0.000)		(0.391)		(0.000)
	R-SQ = 0.57		D-W = 2.240		

G - Growth
R - Revision Rate
N - Number of Ships Affected

R-SQ - R-Squared Statistic
D-W - Durbin-Watson Statistic

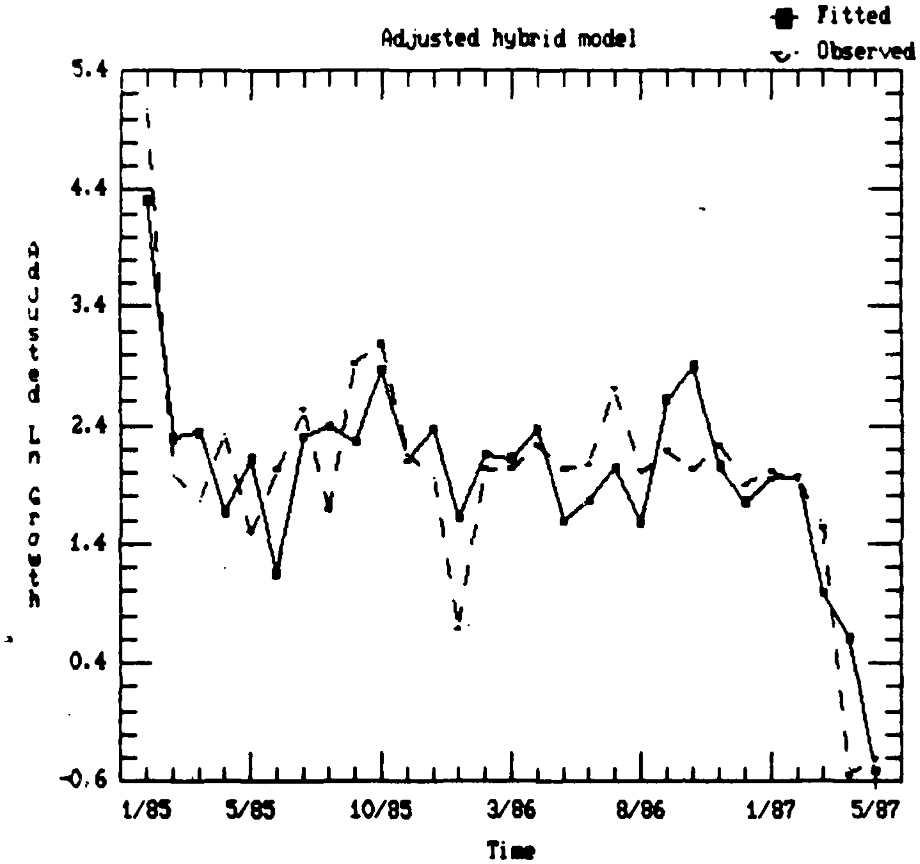

Figure 8. Predicted and Observed Values vs. Time

Adjusted Hybrid Model

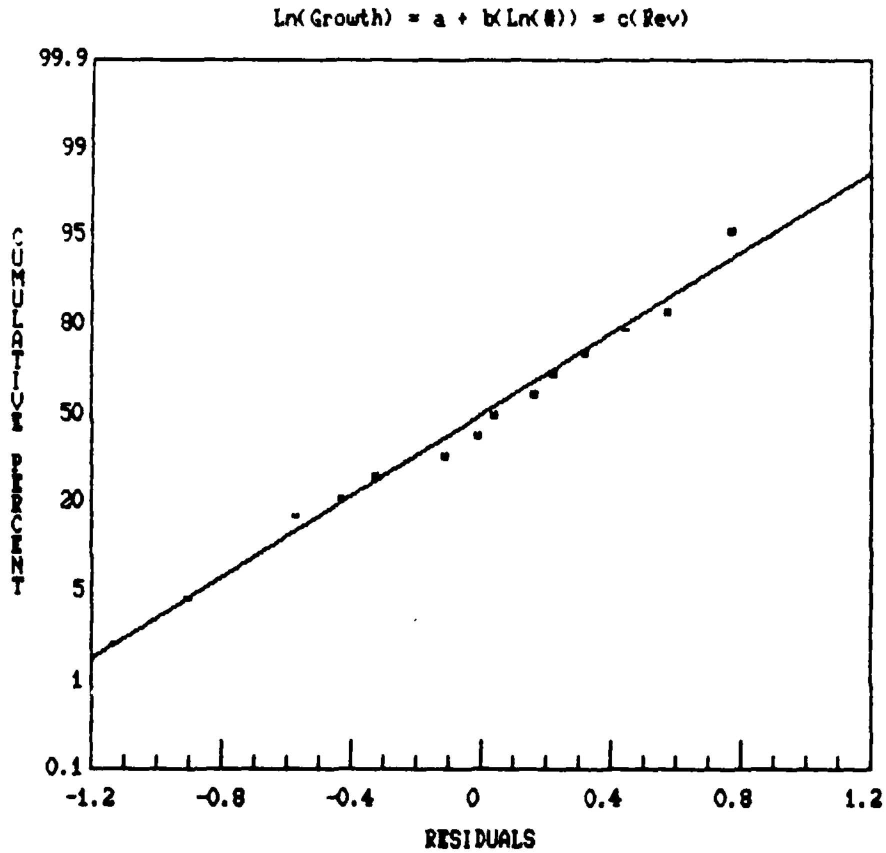

Figure 9. Normal Q-Q Plot

Adjusted Hybrid Model

To confirm the fact that revision rate had no significant effect, the Log /Log model using only the number of ships affected was adjusted for serial correlation in the same manner described above and a regression on the adjusted variables performed. The results were virtually the same (see Table 6) as the hybrid model indicating revision rate had little effect on the chosen response variable, growth defined using budget data.

TABLE 6

REGRESSION STATISTICS FOR COMPARISON

Variant)	Estimated Coefficients (Significance Level)		
	Adjusted Hybrid Model		
1) lnG =	1.01 (0.000)	- 0.02(R) (0.391)	+ 3.17(lnN) (0.000)
	R-SQ = 0.67	D-W = 2.240	
	Adjusted Model, N Only		
2) lnG =	0.96 (0.000)		+ 3.10(lnN) (0.000)
	R-SQ = 0.67	D-W = 2.173	

G - Growth
R - Revision Rate
N - Number of Ships Affected

R-SQ - R-Squared Statistic
D-W - Durbin-Watson Statistic

IV. RESULTS AND CONCLUSIONS

The original hypothesis, that revision rate is directly related to cost growth during SHIPALT installation, was only weakly supported by the data used in this study. It is believed that the hypothesis is sound and the fault lies with the data, specifically the response variable. Several reasons exist for the failure of the model to support the hypothesis and these will be discussed in detail.

A. REASONS FOR MODEL FAILURE - NOISE IN THE RESPONSE

1. Estimates vs. Actuals

As discussed in the chapter on database selection, lack of complete data in any central location precluded the use of actual return cost data for model construction. By defining growth as the difference between the amount programmed and the amount funded for a given ship, the growth figure is actually reflecting the accuracy of NAVSEA's estimates for budget purposes rather than any actual cost growth experienced in contract administration. While the amount funded to a SUPSHIP for a contract closely reflects the contract award price, the amount funded initially is only 90% of the contract award price upon contract award and also includes long lead time Government Furnished Materials and advance design work. Eventually,

NAVSEA has to fund to at least 100% of the contract award price as well as fund any growth.

2. Long Run Approach to Estimates

As previously noted, the amount funded is not a static amount, but rather a dynamic balance which approaches the programmed amount as time progresses. Therefore, growth, as defined, will show an apparent decrease through time for a given ship. This effect is evident in Figure 10, as can be seen in a comparison of the aggregate growth for the FFG-7 class in 1985 and 1986. The 1985 growth data are consistently lower than the 1986 data, even after adjusting for inflation. This is presumably due to the longer period the 1985 data have had to approach the programmed amount.

3. Effect of Learning on Estimate Accuracy

Another trend which can be seen in the data is the effect of NAVSEA's continuous review process of their budget estimates. Comparing the 1986 and 1987 data shows the apparent growth for 1987 decreasing. This is most likely due to NAVSEA's revising their budget estimates downward following a review of their 1986 program amounts for the FFG-7 class. This change in estimate procedures can cause the apparent growth to either increase or decrease.

4. Sensitivity to Bidding Practice of Contractors

NAVSEA's practice of funding to 90% of the contract award price makes this data set extremely vulnerable to a low bid by a contractor. An artificially low award price

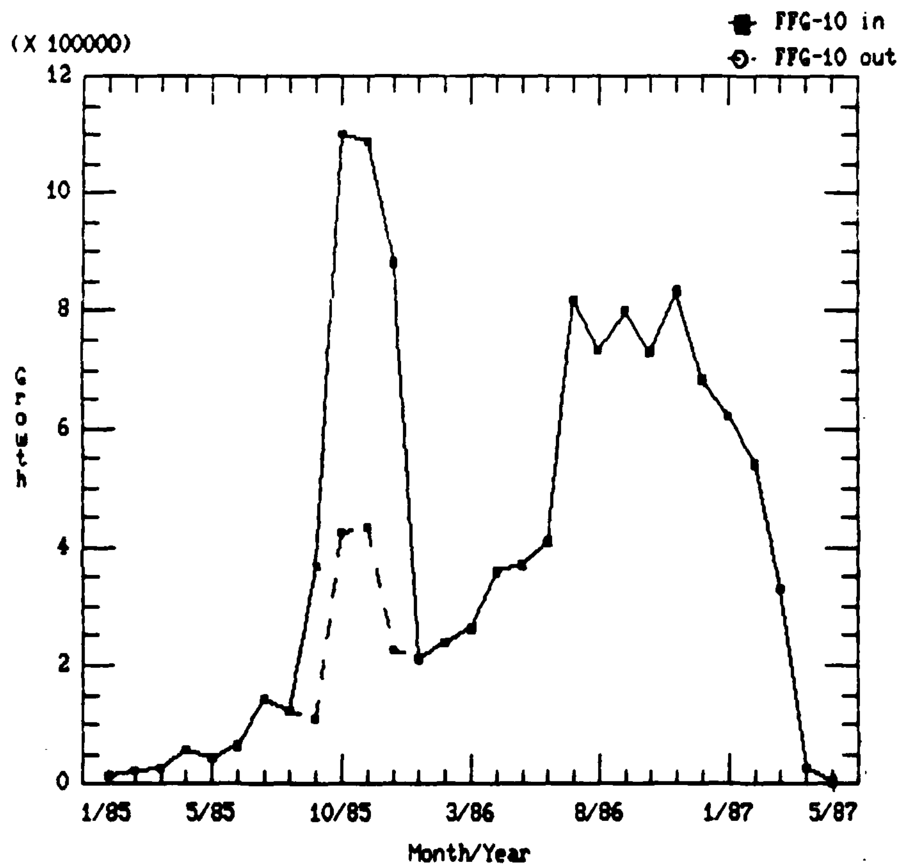

Figure 10. Growth vs. Time

With and Without the FFG-10

will result in a low funding level and a disproportionately large amount of apparent growth on that specific contract. A prime example of this problem is the FFG-10's effect on monthly cost growth data for the period of its contract, 9/85 - 12/85. A major share of the growth attributed to those months is comprised of the one contract on the FFG-10. This can be seen in Figure 10, which is a plot of Growth vs. Time with the FFG-10 in the data base and the FFG-10 out of the data base.

B. INSIGHTS GAINED

1. Revision Rate

The revision rate, as measured at the EPY, seems to be inversely related to EPY product quality. Although this study provides no conclusive relationship between EPY product quality and cost growth, this is most likely due to the choice of the response variable and the fact that any influence of the revision rate on growth is lost among the other contributing factors to "growth" variability.

Initially, revision rate was thought to capture the "snowball" effect as well as the product quality. Upon further analysis, this did not appear to be the case. An additional explanatory variable is needed to establish this important characteristic.

2. The Snowball Effect

To establish the fact that more ships are affected by a drawing revision than merely the ship initiating the LAR, one of two potential variables can be included in the model.

a. Number of Ships Potentially Affected

As discussed in the database development chapter, this was taken to be all ships in an availability or within 4 months of their availability start date. This number could just as easily have been all ships in an availability or all ships in an availability or within 6 months of their availability start date, whichever scenario fits the situation. The point to remember is that this number is an upper limit since not all ships with contracts already awarded are necessarily affected by a particular drawing revision.

b. Number of Reverse LAR's Issued

A more accurate measure of the number of ships affected by a specific drawing revision is the number of reverse LAR's issued by the EPY since reverse LAR's are only issued to affected ships. This measure was not used since the procedure was not implemented until 1986.

3. Serial Correlation

The strong positive serial correlation evidenced by the Durbin-Watson statistics and the residual plots of all model forms was a significant but not surprising result

since each availability covers several time periods. By estimating the coefficient of serial correlation and adjusting the variables accordingly, the fit of the model can be greatly enhanced.

C. POTENTIAL APPLICATION OF THE METHODOLOGY

Should this method produce satisfactory results in further work with a proper response variable, it can potentially be used for evaluating the impact of the quality of planning yard documents on installation cost growth for any large class of ships with a short availability cycle. The basic assumptions are simply that the availabilities are of short enough duration to warrant averaging the growth over the period of the availability and that all contracts are of generally the same type, e.g., fixed price.

V. RECOMMENDATIONS

A. FUTURE AREAS TO EXPLORE

1. AUTOMATED ACCOUNTING DATA -- STAR

With the SUPSHIP's online with STAR, the ability to obtain actual expenditure data instead of estimates will likely be the single most significant factor in determining the extent to which revision rate, as a measure of EPY product quality, affects cost growth. This will allow the calculation of actual cost growth on a given contract. Additional information needed will be the SUPSHIP estimate of NAVSEA and the TYCOM shares of both the award price and the final price.

2. Reverse LAR's

Using reverse LAR's as the measure of how many ships are affected by a revision will accomplish two things. First, ships not affected will not be counted. Second, the arbitrary A-minus date is no longer a factor to be considered since it is already considered in determining which ships receive reverse LAR's.

3. Verification

In the case of the FFG-7 Class and its EPY, Long Beach Naval Shipyard, the SUPSHIP's are currently providing informal feedback in the form of estimated cost growth attributable to a specific revision. Since this is exactly

the relationship this study is attempting to establish, any future efforts using this methodology will have an alternative source against which to verify the results.

B. MODEL FORM

The most promising functional form of the model is the hybrid model with the number of ships affected as a multiplicative form and the revision rate as an exponential form. This model seems to have the best distribution of residuals and has a good representation of the interrelationship of the two proposed factors which influence cost growth. Adjusting the data for serial correlation will significantly reduce the uncertainty in the fitted model for whatever form is chosen, and will also allow more accurate forecasts of the EPY's impact on the installing activities.

APPENDIX A

Glossary

Availability: Overhaul period for a given ship.

Availability Cycle: The time between availabilities for a given ship.

Drawing Schedule: List of all applicable drawings for a given ship and a given SHIPALT.

Expanded Planning Yard (EPY): The planning / design activity for SHIPALT development.

Fleet Modernization Program (FMP): The overall program for prioritizing, programming, planning, and implementing improvements to existing ships.

Funding: The obligation of money to various accounts.

Liaison Action Record (LAR): A request from an installation activity to the EPY for design assistance. Resolution requires either: 1) clarification of existing drawings or, 2) revision, addition, deletion of existing drawings.

Naval Sea Systems Command (NAVSEA): The Chief of Naval Operation's (CNO) agent for execution of the FMP.

Program: 1) In a planning sense, the assignment of a set of SHIPALT's to be accomplished on a given ship during a specified availability.
2) In a fiscal sense, the assignment of money to different accounts.

Ship Alteration (SHIPALT): A design package to update an existing system on, add a new system to, or remove an old system from a given ship class.

Ship Class: All ships sharing a common design, e.g., the FFG-7 class.

Supervisor of Shipbuilding, Conversion, and Repair (SUPSHIP): The contracting activity for installation of SHIPALT's and overhaul of ships in the private sector.

APPENDIX B

Raw Growth Data by Hull

Fiscal Program data as recorded in the SAFIRE (budget execution subsystem) data base as of December, 1987. Raw, unadjusted data with growth as defined for this study,

Growth = Curr. Prog. - Tot. Funded.

East Coast FY85 availabilities:

Hull	Current Funded	+	Prior Funded	=	Total Funded	Current Program	Growth (Diff)
11	2233797		100000		2333797	2489332	155535
13	2349267		113849		2463116	2784118	321002
22	556656		128891		685547	690627	5080
26	603270		177792		781062	781928	866
28	605746		109462		715208	725766	10588
29	749760		116330		866090	878461	12371
32	627508		100000		727508	749298	21790
34	1045164		100000		1145164	2034509	889345

East Coast FY86 availabilities:

Hull	Current Funded	+	Prior Funded	=	Total Funded	Current Program	Growth (Diff)
7	2506496		413345		2919841	3686566	766725
15	2075863		434438		2510301	2678362	168061
21	2263729		8709		2272438	3138785	866347
26	1178305		168550		1346855	3230284	1883429
31	787894		314234		1102128	1183707	81579
36	721730		3686		725416	757917	32501
39	729292		3580		732872	787806	54934
42	100000		0		100000	594961	494961

East Coast FY87 availabilities:

Hull	Current Funded	+	Prior Funded	=	Total Funded	Current Program	Growth (Diff)
20	2744158		460919		3205077	3988077	783000
24	3681043		313165		3994208	4041708	47500
40	18217		35665		53882	112913	59031
45	87677		30475		118152	175475	57323

West Coast FY85 availabilities:

Hull	Current Funded	+	Prior Funded	=	Total Funded	Current Program	Growth (Diff)
9	4486575		69396		4555971	4555971	0
10	3136336		50000		3186336	5443473	2257137
23	1783829		86156		1869985	1908821	38836
25	1310466		84120		1394586	1416863	22277
27	1270786		70000		1340786	1466665	125879

West Coast FY86 availabilities:

Hull	Current Funded	+	Prior Funded	=	Total Funded	Current Program	Growth (Diff)
12	1939083		454607		2393690	2504029	110339
14	3639025		391908		4030933	4658183	627250
19	3376555		196056		3572611	3920344	347733
30	805895		184665		990560	1547707	557147
33	633237		125284		758521	1874235	1115714
37	1454164		3060		1457224	1457224	0

West Coast FY87 availabilities:

Hull	Current Funded	+	Prior Funded	=	Total Funded	Current Program	Growth (Diff)
38	205173		5759		210932	310802	99870
41	71901		10665		82566	84865	2299
43	14908		6825		21733	25485	3752

APPENDIX C

Adjusted Growth Data by Hull

Growth data adjusted to 1986, East Coast Dollars
Ordered by hull number.

HULL	GROWTH	START DATE	STOP DATE
7	766725	60501	60828
9	0	50107	50425
10	2249705	50918	51230
11	159983	50401	50802
12	104785	60106	60430
13	330182	50708	51213
14	595679	60401	60724
15	168061	60106	60503
19	330230	61014	70205
20	783000	61103	70225
21	866347	60707	61106
22	5225	51208	60129
23	38707	50103	50509
24	47500	70107	70508
25	22203	50204	50412
26	890	41008	50116
26	1883429	60830	70326
27	125464	50617	50906
28	10859	50301	50517
29	12724	50107	50315
30	529104	60106	60420
31	81579	51125	60219
32	22413	50613	50819
33	1059557	60624	61003
34	914782	50927	51215
36	32501	60213	60512
37	0	60224	60620
38	92902	70202	70403
39	54934	60213	60506
40	59031	70105	70306
41	2138	70105	70213
42	494961	61013	61212
43	3490	70316	70508
45	57323	70203	70410

Growth data adjusted to 1986, East Coast Dollars.
Ordered on availability start date.

HULL	GROWTH	START DATE	STOP DATE
26	890	41008	50116
23	38707	50103	50509
9	0	50107	50425
29	12724	50107	50315
25	22203	50204	50412
28	10859	50301	50517
11	159983	50401	50802
32	22413	50613	50819
27	125464	50617	50906
13	330182	50708	51213
10	2249705	50918	51230
34	914782	50927	51215
31	81579	51125	60219
22	5225	51208	60129
12	104785	60106	60430
15	168061	60106	60503
30	529104	60106	60420
36	32501	60213	60512
39	54934	60213	60506
37	0	60224	60620
14	595679	60401	60724
7	766725	60501	60828
33	1059557	60624	61003
21	866347	60707	61106
26	1883429	60830	70326
42	494961	61013	61212
19	330230	61014	70205
20	783000	61103	70225
40	59031	70105	70306
41	2138	70105	70213
24	47500	70107	70508
38	92902	70202	70403
45	57323	70203	70410
43	3490	70316	70508

APPENDIX D

Growth by Month, Derivation

Growth per month by hull, calculated by computing daily average and multiplying by the number of days that hull was in an availability in a given month. Totalling each column yields the time series growth data used for the analysis.

MONTH/YEAR

HULL	1/85	2/85	3/85	4/85	5/85	6/85	7/85
26	142	0	0	0	0	0	0
23	8602	8602	9523	9216	2765	0	0
9	0	0	0	0	0	0	0
29	4558	5317	2849	0	0	0	0
25	0	7953	10273	3977	0	0	0
28	0	0	4316	4177	2367	0	0
11	0	0	0	38706	39996	38706	39996
32	0	0	0	0	0	5687	10370
27	0	0	0	0	0	20136	48017
13	0	0	0	0	0	0	46268
10	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0
TOT	13301	21872	26961	56075	45127	64529	144651

MONTH/YEAR

HULL	8/85	9/85	10/85	11/85	12/85	1/86	2/86
26	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0
11	2580	0	0	0	0	0	0
32	6356	0	0	0	0	0	0
27	48017	9294	0	0	0	0	0
13	65195	63092	65195	63092	27340	0	0
10	0	262102	677096	655254	655254	0	0
34	0	34739	358965	347386	173693	0	0
31	0	0	0	22048	22783	22783	13964
22	0	0	0	0	2311	2914	0
12	0	0	0	0	0	22979	25737
15	0	0	0	0	0	35910	40220
30	0	0	0	0	0	127188	142451
36	0	0	0	0	0	0	5540
39	0	0	0	0	0	0	10049
37	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0
TOT	122149	369226	1101256	1087780	881381	211775	237960

MONTH/YEAR

HULL	3/86	4/86	5/86	6/86	7/86	8/86	9/86
26	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0
12	28494	27575	0	0	0	0	0
15	44529	43093	4309	0	0	0	0
30	157714	101751	0	0	0	0	0
36	11449	11080	4432	0	0	0	0
39	20768	20098	4020	0	0	0	0
37	0	0	0	0	0	0	0
14	0	155395	160574	155395	124316	0	0
7	0	0	198071	191681	198071	178903	0
33	0	0	0	62944	325211	325211	314720
21	0	0	0	0	170429	220137	213036
26	0	0	0	0	0	9055	271648
42	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0
TOT	262954	358991	371406	410020	818026	733305	799404

MONTH/YEAR

HULL	10/86	11/86	12/86	1/87	2/87	3/87	4/87
26	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
33	31472	0	0	0	0	0	0
21	220137	42607	0	0	0	0	0
26	280703	271648	280703	280703	253539	235429	0
42	148488	247481	98992	0	0	0	0
19	49245	86903	89799	89799	14484	0	0
20	0	185447	212921	212921	171711	0	0
40	0	0	0	25580	27548	5903	0
41	0	0	0	1425	713	0	0
24	0	0	0	9421	10992	12169	11777
38	0	0	0	0	40258	47999	4645
45	0	0	0	0	21713	26924	8685
43	0	0	0	0	0	988	1975
TOT	730046	834086	682416	19851	40956	329413	27083

MONTH/YEAR

HULL	5/87
26	0
23	0
9	0
29	0
25	0
28	0
11	0
32	0
27	0
13	0
10	0
34	0
31	0
22	0
12	0
15	0
30	0
36	0
39	0
37	0
14	0
7	0
33	0
21	0
26	0
42	0
19	0
20	0
40	0
41	0
24	3140
38	0
45	0
43	527
TOT	3667

APPENDIX E

Time Series Variables

MO/YR	GROWTH	REVISIONS	# SHIPS AFFECTED
1/85	13301	0	7
2/85	21872	5	8
3/85	26961	8	9
4/85	56075	10	8
5/85	45127	4	8
6/85	64529	2	6
7/85	144651	6	7
8/85	122149	5	8
9/85	369226	12	9
10/85	1101256	3	11
11/85	1087780	7	11
12/85	881381	11	12
1/86	211775	12	10
2/86	237960	10	10
3/86	262954	10	10
4/86	358991	13	11
5/86	371406	9	9
6/86	410020	5	8
7/86	818026	4	8
8/86	733305	6	7
9/86	799404	13	9
10/86	730046	2	11
11/86	834086	9	11
12/86	682416	15	10
1/87	619851	5	9
2/87	540956	12	9
3/87	329413	1	6
4/87	27083	1	4
5/87	3667	1	2

APPENDIX F

Autocorrelation Adjustment

In ordinary least squares estimation procedures, it is assumed that the residuals have a constant variance and zero mean. The regression coefficients, β, are estimated using a model of the form,

$$y = X\beta + e$$

The first order autocorrelation indicated by the Durbin-Watson statistics is a special case of the above model where the constant variance assumption is violated. To regain a constant variance, the model is modified by assuming the residuals are stochastic quantities partially determined by previous observations. In this case,

$$e_t = r\, e_{t-1} + v_t$$

and v has constant variance with zero mean.

To accomplish this transformation, a coefficient of serial correlation is estimated using the Durbin-Watson statistic from the unadjusted regression model,

$$\hat{r} = 1 - (D.W. / 2)$$

The variables are then adjusted in the following manner,

for t = 2,T

$$y_t^* = y_t - \hat{r} y_{t-1}$$
$$x_t^* = x_t - \hat{r} x_{t-1}$$

for t = 1,

$$y_1^* = (1 - \hat{r}^2)^{0.5}\, y_1$$
$$x_1^* = (1 - \hat{r}^2)^{0.5}\, x_1$$

After adjusting the variables, the regression coefficients are estimated using least squares on the transformed model

$$y^* = X^*\beta + e^*$$

The following table contains the raw and adjusted data for the hybrid model form discussed in Chapter 3.

$\hat{r} = .844$

G -- GROWTH
-- NUMBER OF SHIPS AFFECTED
Rev -- REVISION RATE

	Unadjusted Data			Adjusted Data		
Mo/Yr	Ln(G)	Ln(#)	Rev	Ln(G)	Ln(#)	Rev
1/85	9.50	1.95	0.00	5.085	1.042	0.000
2/85	9.99	2.08	5.00	1.974	0.436	5.000
3/85	10.20	2.20	8.00	1.763	0.441	3.778
4/85	10.93	2.08	10.00	2.319	0.224	3.244
5/85	10.72	2.08	4.00	1.483	0.323	-4.445
6/85	11.07	1.79	2.00	2.024	0.036	-1.378
7/85	11.88	1.95	6.00	2.529	0.433	4.311
8/85	11.71	2.08	5.00	1.679	0.436	-0.067
9/85	12.82	2.20	12.00	2.928	0.441	7.778
10/85	13.91	2.40	3.00	3.086	0.542	-7.134
11/85	13.90	2.40	7.00	2.151	0.373	4.467
12/85	13.69	2.48	11.00	1.951	0.460	5.089
1/86	12.26	2.30	12.00	0.703	0.204	2.710
2/86	12.38	2.30	10.00	2.024	0.358	-0.134
3/86	12.48	2.30	10.00	2.025	0.358	1.555
4/86	12.79	2.40	13.00	2.252	0.453	4.555
5/86	12.83	2.20	9.00	2.023	0.172	-1.979
6/86	12.92	2.08	5.00	2.093	0.224	-2.601
7/86	13.61	2.08	4.00	2.700	0.323	-0.223
8/86	13.51	1.95	6.00	2.008	0.190	2.622
9/86	13.59	2.20	13.00	2.186	0.554	7.933
10/86	13.50	2.40	2.00	2.023	0.542	-8.979
11/86	13.63	2.40	9.00	2.233	0.373	7.311
12/86	13.43	2.30	15.00	1.919	0.278	7.400
1/87	13.34	2.20	5.00	1.993	0.253	-7.668
2/87	13.20	2.20	12.00	1.938	0.342	7.778
3/87	12.71	1.79	1.00	1.557	-0.064	-9.134
4/87	10.21	1.39	1.00	-0.523	-0.127	0.155
5/87	8.21	0.69	1.00	-0.412	-0.478	0.155

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